INVESTIGATION OF DIESEL FUEL FIRE VULNERABILITY PARAMETERS IN ARMORED PERSONNEL CARRIERS DUE TO BALLISTIC PENETRATION

INTERIM REPORT
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A series of full-scale ballistics tests were conducted to evaluate the diesel fuel fire vulnerability parameters in armored personnel carriers due to penetration by 90-mm HEAT rounds. The tests considered fuel cell penetration through 1.5-inch aluminum armor with the four variables: fuel temperature, fuel antimisting additive concentration, air availability, and Halon 1301 fire-suppression system. The test results are summarized in this report.

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FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, TX, under Contract Nos. DAAK70-82-C-0001 and DAAK70-85-C-0007 and covers the period March 1984 to March 1985. Contractor's representative was Mr. F.W. Schaekel, Materials, Fuels, and Lubricants Laboratory/STRBE-VF.

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I. INTRODUCTION

The U.S. Army has a special requirement for a diesel fuel that will perform satisfactorily in diesel-powered combat vehicles, but would self-extinguish in case of ignition by ballistic penetration or other unwanted ignition sources. The main thrust for this investigation was experience which indicated that fuel fires can be a major cause of ground vehicle and personnel losses. If catastrophic fuel fires could be eliminated, personnel would have increased chances for survival, and chances of repair or salvage of vehicles would be improved. Thus, cost effectiveness would be realized not only in reduced key personnel losses, but also through improved supply of critical tactical equipment in an area where resupply may be impossible.

A. Background Information

Six generations of fire-resistant fuel have been investigated by the Army, and these are summarized in Table 1.(1,2)* The last approach involves the inclusion of surfactant-stabilized emulsified water in diesel fuel. Screening studies followed by laboratory, bench-scale, and full-scale experimental investigations had led to the development of clear-to-hazy fire-resistant microemulsions of 10 vol% water and 12 vol% surfactant premix formulated in DF-2 diesel fuel. Because of complexities resulting from variations in the composition of the base fuel, emulsifying agents, and water, extensive laboratory evaluations of physical and chemical properties had been an essential element of the FRF development program.

Several different flammability evaluation procedures were also employed to define the vulnerability characteristics of FRF candidates (1,2,3), and the results for referee-grade base fuel FRF formulations are summarized in Table 2. Combinations of antimisting agents and aqueous microemulsions were also evaluated. These formulations were most effective in reducing the mist fireball and eliminating pool burning when subjected to 20-mm high explosive rounds. Work on this formation was discontinued because of the need to

* Underscored numbers in parentheses refer to the list of references at the end of this report.

TABLE 1. SIX GENERATIONS OF FIRE-RESISTANT FUEL FORMULATIONS INVESTIGATED BY THE U.S. ARMY

1. Fuel gellation just prior to hazard occurrence (Initiated by U.S. Army Aviation Material Laboratories--1964-1966).
2. Semisolid, but pumpable, fuel-in-water emulsions (Initiated by U.S. Army Aviation Material Laboratories--1965-1970).
3. Viscous-liquid, fuel-in-water emulsions (Initiated by U.S. Army Coating and Chemical Laboratories--1969-1972).
4. High molecular weight polymeric additives for inhibition of mist formation (Initiated by U.S. Army Coating and Chemical Laboratories--1971).
5. Volatile halogenated fire suppressant as fuel constituent (Initiated by U.S. Army Ballistic Research Laboratories--1972-1976).
6. Nonviscous, water-in-fuel emulsions (Initiated by Fuels and Lubricants Division, Energy and Water Resources Laboratory, U.S. Army Mobility Equipment Research and Development Command--1976).

TABLE 2. REFEREE-GRADE BASE-FUEL FIRE-RESISTANT FUEL FLAMMABILITY PROPERTIES

Referee-Grade Base Fuel MIL-F-46162A(MR)II	Neat Base Fuel	Base Fuel Plus 10 Vol% Water Plus 6% Surfactant
Flame propagation across bulk liquid surface at 77°C	Wick burning with simultaneous propagation	Wick burning only
Burns on wick at 25°C	Yes	Yes
Flammability of fuel mist at 25°C (Mist Flashback Test)	Extreme	Moderate
Ballistic tests at 77°C (20-mm HEAT)	Catastrophic fire	Transient fireball with self-extinguishing ground fire
Flash Point, °C	61	65*
Fire Point, °C	91	---
Autoignition Temperature, °C	224	405

*Pilot flame in Penske-Martens apparatus often extinguished by water vapor

accelerate the fielding of the 10 percent aqueous microemulsion. These flammability evaluations demonstrated that such aqueous microemulsions yielded diminished mist flammability while either eliminating pool burning or providing rapid self-extinguishment f pool fires, even at fuel temperatures more than 10°C above the base fuel flash point.

Medium-scale ballistic tests, using 20-mm high-explosive incendiary tracer projectiles fired into fuel drums, and full-scale ballistic tests on M-113 and M-48 using 3.2-in. (81-mm) precision-shaped charges correlated with the flammability data.(4) The tests in Reference 4 were conducted with a fuel test temperature of 77°C, which has been reported bulk fuel temperatures in desert operations.

The FRF has an excellent fire resistance; however, logistical constraints and low-temperature instability of the microemulsion-type FRF lead to a search for additional approaches to fire reduction. A Short-Term Advisory Services (STAS) team examined several proposed approaches, and recommended the ones which were believed to hold potential for development and deployment. These included fuel cooling, fuel flash point modification, halon compartment deluge, and fuel line closure systems. It was also recommended that with fuel cooling and suitable fuel systems modifications, conventional antimisting agents may have some potential for reducing aerosol formation.(5)

B. Objectives of Investigation

The purpose of the full-scale ballistic tests described in this report was to evaluate how fire vulnerability is affected by some of the STAS-recommended approaches to diesel fuel in armored vehicle fuel cells. The tests considered four variables: fuel temperature, air availability, antimisting additive concentration, and halon fire suppression.

II. APPROACH

Arrangements were made for a series of full-scale ballistic tests to be conducted by the TERA group of New Mexico Institute of Mining and Technology, Socorro, NM. The tests considered armored personnel carrier (APC M113)-type fuel cell location protected by a 1.5-inch (38 mm) thick aluminum armor plate. A 90-mm HEAT round was fired through the armor into the fuel tank mounted against the interior wall of the vehicle. The aluminum fuel cells were fabricated by TERA. Diesel fuel (DF-2) with a flash point of 142°F (61°C) was furnished by TERA as purchased from a local supplier, and a dedicated fuel tank was provided for its storage. AFLRL personnel participated in the planning and conducting of the test.

The tests considered fuel cooling, effect of ventilation, antimisting additives, and halon fire suppression.

A. General Test Description

An M84, armored personnel carrier (APC) was fitted with an aluminum armor plate (from a M113), through which a 90-mm HEAT round was fired into a nominal 60-gal. (227-liter) capacity aluminum fuel cell (Figures 1 and 2) containing 50 gal. (189 liters) of fuel.

The fuel cells were fabricated by TERA from 1/8-inch (3 mm) thick aluminum plates with the dimensions of 40 in. (101 cm) wide X 30 in. (76 cm) high X 13 in. (33 cm) deep. The fuel cell was held against right hand wall in the rear corner by two steel bands as shown in Figure 3.

The round penetrated the fuel cell and liquid through the approximate geometric center of 40 in. X 30 in. (101 cm X 76 cm) walls. The action inside the APC was observed by a 400-frame/second camera which had visual access through a hole cut in the APC's left wall (See Figure 4). Two other cameras, one real time and one 1000 frame/second, observed the action from a position 200 feet (61 meters) to the rear of the APC.

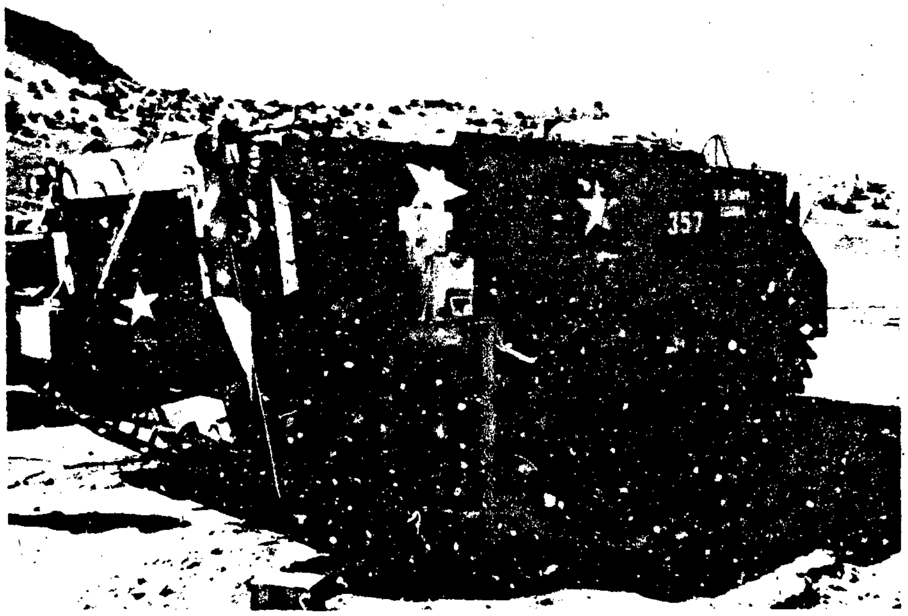

FIGURE 1. ARMORED PERSONNEL CARRIER

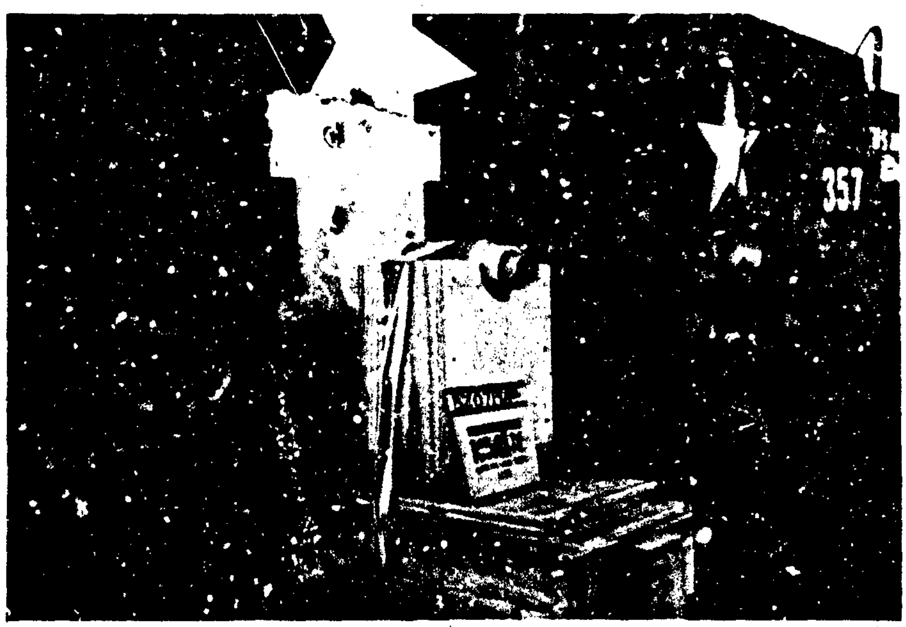

FIGURE 2. ALUMINUM ARMOR PLATE AND HEAT ROUND

FIGURE 3. THE FUEL TANK

FIGURE 4. 4CO-FRAME/SECOND CAMERA VIEWING INSIDE VIEW

The fuel was either cooled with an immersion coil refrigeration unit or heated with an electric immersion heater. The air availability inside the personnel compartment was varied by a ventilation fan, and ramp or personnel entry door in the ramp. The M84 had a false floor of steel plates separated by a gap of approximately 8 in. (20 cm) above the bottom armor. During the first three tests, it was observed that the fuel that spilled from the fuel cell during ballistic penetration collected under this false floor which had limited air. Thus, this condition influenced the fire development from test to test. Therefore, the false floor plates were removed for the remaining tests.

The halon fire suppression system used in the test was developed by U.S. Army Tank-Automotive Command (TACOM) for M-113 vehicles, and was used in consultation with the TACOM personnel. The system used two sensors facing the ramp from the vicinity of the driver compartment. The Halon 1301 dispensers were located on one of the armored walls so as to flood the personnel compartment between the ramp and the fuel cell with the fire extinguishing agent (monobromo-trifluoro methane) upon signal from the fire sensors. Each of the dispensers contained 7 pounds (3.2 kg) of Halon 1301 under 750 psi (5.2 MPa) nitrogen as a propellant.

The instrumentation for the tests included pressure and temperature monitors for the fuel cell and the personnel compartment.

B. Fuel and Additives

The antimisting agent (AM-1) used was a proprietary high molecular weight polymer solution. The viscosity/concentration data of the AM-1 polymer in solution with the diesel fuel under test are presented as a function of temperature in Table 3. The AM-1 concentrations used for the ballistics tests were nominal 0.2 and 0.35 percent polymer by weight. Table 4 presents the properties of the base diesel fuel (DF-2).

TABLE 3. VISCOSITY OF ANTIMISTING POLYMER SOLUTIONS IN THE TEST BASE FUEL

AM-1 Concentration, Wt%	Viscosity, cSt at 0°C	40°C	100°C
0.0	3.3	1.55	—
0.20	24.3	8.8	4.0
0.35	35.1	15.2	6.8
0.55	99.7	37.9	22.1

TABLE 4. PROPERTIES OF THE DF-2 FUEL USED IN BALLISTICS TESTS

Flash Point, °F (°C)	142 (61)
Cloud Point, °F (°C)	-40 (-40)
Freeze Point, °F (°C)	-47 (-44)
Viscosity, 40°C, cSt	1.55
Viscosity, 0°C, cSt	3.3

III. TEST RESULTS AND DISCUSSION

A. Test Results

A series of 15 tests were conducted using 90-mm HEAT rounds fired through a 1.5-in. (38-mm) aluminum armor into the fuel cells containing 50 gal. (189 liters) of fluid. The fuel cell was perforated through the approximate center of the 40 in. long X 30 in. (101 cm X 76 cm) vertical sides, and the fuel liquid level before each test was approximately 9 in. (23 cm) above this center.

The summary of test conditions and results are presented in Table 5. A total of six tests were conducted on the fuel cells containing neat diesel fuel. Five of these tests showed no effect of the fuel cooling on pool fire development, with the fuel bulk temperature between 36°F (2°C) and 42°F (6°C). The sixth test with neat fuel, which had a flash point of 142°F (61°C), (Test No. 12) was conducted with the fuel temperature of 170°F (77°C) to con-

TABLE 5. SUMMARY OF TEST CONDITIONS AND RESULTS

Test No.	Fuel	Fuel Temp., °F(°C)	Ventilation Fan	Door	False Floor	Halon 1301 System	Pool Fire
1	DF-2	41(5)	Off	STBO[a]	In	No	Yes
2	DF-2	41(5)	Off	Closed	In	No	Yes
3	DF-2	36(2)	On	Closed	In	No	Yes
4	DF-2	42(6)	On	STBO	R[b]	No	Yes
5	DF-2	38(3)	On	STBO	R	No	Yes
6	0.2 Wt.% AM-1 in DF-2	60(16)	On	Open	R	No	Yes
7	0.2 Wt.% AM-1 in DF-2	65(18)	Off	STBO	R	No	Yes
8	0.2 Wt.% AM-1 in DF-2	38(3)	Off	STBO	R	No	Yes
9	0.35 Wt.% AM-1 in DF-2	61(16)	On	RD[c]	R	No	No
10	0.35 Wt.% AM-1 in DF-2	58(14)	On	RD	R	No	No
11	0.35 Wt.% AM-1 in DF-2	170(77)	On	RD	R	No	Yes
12	DF-2	170(77)	Off	Closed	R	Yes	No
13	0.2 Wt.% AM-1 in DF-2	170(77)	Off	Closed	R	Yes	No
14	Water	46(8)	Off	RD	R	No	No
15	0.35 Wt.% AM-1 in DF-2	125(52)	On	RD	R	No	Yes

[a]STBO: Door set to blow open from blast pressure
[b]R: Removed
[c]RD: Ramp down

firm a proper installation and operation of the Halon 1301 fire suppression system. The halon fire suppression system was then used to evaluate its efficacy with 0.2 Wt% AM-1 containing diesel fuel at 170°F (77°C). The effect of fuel cooling was also evaluated with two concentrations of antimisting agent in the diesel fuel (Test Nos. 6 to 10). The higher concentration of antimisting agent (0.35 wt.%) effectively showed no residual pool burning of the fuel at approximately 60°F (16°C) bulk fuel temperature. The tests at 125°F (52°C) and 170°F (77°C) temperature of the bulk fuel of this same antimisting composition resulted in development of intense pool fires. A test was also conducted with the fuel cell containing water to record the baseline effect of a 90-mm HEAT round fired through the armor and the cell.

The overall results from Table 5 indicate the following:

(a) No benefit in fire vulnerability reduction resulted in decreasing the fuel bulk temperature below the flash point by approximately 100°F (38°C).

(b) The addition of antimisting agent in high concentrations (see viscosity data in Table 3) significantly reduced the mist fireball and, therefore, reduced the likelihood of a pool fire, especially at mild fuel bulk temperatures of approximately 60°F (16°C). The tendency of these blends for development of intense pool fire near the flash point temperature of the base fuel, however, shows that no quantitative correlation between the concentration of AM-1 and fuel temperature below which pool fires do not occur can be made from the limited data.

(c) The Halon 1301 fire suppression system effectively controlled pool fire resulting from antimisting additive containing fuel at temperatures of 170°F (77°C). The Halon 1301 also controlled pool burning of neat base fuel at 170°F (77°C).

The effect of fuel cell rupture-perforation geometry, mist-fireball size, the fuel flow path, quenching objects, ventilation geometry, and oxygen availability had effects on the size and intensity of the fires developed in all

cases. The last column in Table 5, for brevity, does not distinguish very small fires from very intense fires, but rather emphasizes the events in which there was no possibility of sustained pool fire. The following section discusses briefly the more significant tests. The data sheet summaries furnished by TERA are included in this report as an appendix.

B. Discussion

The first five tests with neat diesel fuel showed the effect of limited air availability and quenching on the development of fire inside the personnel compartment. The M84 APC had a false floor of steel plates separated by an air gap of about 8 in. (20 cm) above the bottom armor. It was observed during the first three tests that the burning fuel dumped on the floor from the ruptured cell. A major portion of this fuel readily flowed between the false floor plates, and it collected on the bottom armor. The oxygen supply in the gap between the armor and the floor plate was limited and could not be replenished by ventilation in the personnel compartment. As in Test No. 1 with the door open and the APC apparently full of available oxygen, the fuel trapped beneath the false floor was unable to burn. Thus, a large portion of the spilled burning fuel was separated from air by a sizable heat sink. The residual pool fire over the false floor plate was easily put out by a fire extinguisher as in Test No. 1 or was suffocated due to the door closure as in Test Nos. 2 and 3. A sustaining pool fire needs a large supply of air entering near the liquid level, such as natural ventilation set up in Test Nos. 4 and 5 with the door open and false floor plates removed from the personnel compartment. The intense pool fires developed in these two tests could not be successfully extinguished with dry powder-type fire extinguishers, but were easily suffocated by closing the rear door. The reduction in the bulk temperature of the neat fuels by as much as 100°F (38°C) below the flash point did not prevent the probability of the pool fires under the conditions of these tests.

Test Nos. 6 and 7 were conducted with 0.2 wt% antimisting agent (high molecular weight polymer) in the diesel fuel. This concentration of the polymer increases the base fuel viscosity from 1.55 to 8.8 cSt at 40°C and from 3.3

to 24.3 cSt at 0°C. The ballistic test Nos. 6 and 7 conducted at fuel temperatures of approximately 60°F (16°C) with this modified fuel showed no reduction in the development of the pool fire, while the mist fireball size was reduced. A test (No. 8) at 38°F (3°C), however, demonstrated a significant reduction in the size of the pool fire, while not completely eliminating its occurrence.

The next series of tests were conducted with increased concentration of AM-1 in the diesel fuel (0.35 wt%). The ramp of the APC was let down during these tests to aid in photographic coverage of the events. The tests (Nos. 9 and 10) conducted at the fuel bulk temperatures of 60°F (15°C) showed signicant reduction in the size of the mist fireball and prevented pool fires. The tests conducted with the same modified fuel at 125°F (51°C) slightly below the base fuel flash point temperature (Test No. 15) and at 170°F (Test No. 11) resulted in very large and intense pool fires.

The tests conducted with Halon 1301 fire suppression system (Test Nos. 12 and 13) used bulk fuel temperatures of 170°F (77°C). The fire suppression system effectively put out the fires resulting from both base fuel and 0.2 wt% AM-1 containing fuel.

IV. CONCLUSIONS AND RECOMMENDATIONS

A series of ballistic tests on armored personnel carriers were conducted to evaluate the fire vulnerability parameters due to penetration of the fuel cells by 90-mm HEAT rounds. The tests considered effects of fuel temperature, antimisting additive concentration, air availability, and Halon 1301 fire suppression. The results of this investigation can be summarized as follows:

1. No benefit occurred in fire vulnerability reduction by fuel cooling.

2. Fuel cooling accompanied by a high concentration of antimisting agent (0.35 wt% AM-1) has potential for preventing pool fire, and reduces the mist fireball.

3. Antimist additive was not effective in reducing pool fires at bulk fluid temperatures near or above base fuel flash point.

4. The Halon 1301 fire suppression system effectively controls fires resulting from neat fuel or fuel containing antimist agent.

5. Air availability in the personnel compartment or quenching of fires due to heat sinks reduces duration and size of fires, thus indicating that a design modification could possibly be incorporated that would be effective in reducing pool burning.

Recommendations for this program include:

- The fuel cell develops high pressures during the ballistic penetration. This fact could be advantageously used by constructing the fuel tanks with designed "weak links" that dump a major portion of the fuel outside the APC upon penetration.

- The combination of both AM-1 and H_2O was most impressive with regard to fire reduction in an earlier series of tests.(6) The optimum quantities of AM-1 and H_2O were not determined in those tests, but it appears that they were synergistic. Parametric variations in the concentrations and the fuel temperatures for optimization with respect to ballistic threat are recommended for further investigation.

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APPENDIX

SUMMARIES OF DATA FROM TERA REPORT

(MDK3.A)

TEST NO. 1: TERA NO. BZ0719A4

1. Conditions:

Date: 19 July 1984
Fuel: 50 gal. (189 liters) of neat diesel
Fuel Temperature: 41°F (5°C)
Shaped Charge: 90-mm HEAT, M371E1
Armor: 1.5-in. (38-mm) aluminum
Door: Closed
Fan: Off
Suppression System: Not applicable

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. One end of the tank was blown off by fuel cell pressure which peaked at 60 psi (414 kPa) (See Figures A-1 through A-3 at the end of this appendix). The fuel was dumped on the floor, and the rear door was blown open. Most of the fuel collected under the armored personnel carrier's false floor where air was very limited (See Figure A-2). Only a very small fire developed, and this was easily put out with a fire extinguisher.

TEST NO. 2: TERA NO. BZ0720A4

1. Conditions:

Date: 20 July 1984
Fuel: 50 gal. (189 liters) of neat diesel
Fuel Temperature: 41°F (5°C)
Shaped Charge: 90-mm HEAT, M371E1
Armor: 1.5-in. (38-mm) aluminum
Door: Closed
Fan: Off
Suppression System: Not applicable

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The end seams split, and the fuel emptied on the floor (See Figures A-4a and A-4b). A small amount of fuel was blown back through the blast entry hole and started a small ground fire. No large pool fire developed. An initial flash followed the shaped charge detonation, but this was quickly suffocated as the oxygen was used up. The suffocation was probably aided by the false floor.

TEST NO. 3: TERA NO. BZ0726A4

1. Conditions:

Date: 26 July 1984

Fuel: 50 gal. (189 liters) of neat diesel

Fuel Temperature: 36°F (2°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Closed

Fan: On

Suppression System: Not applicable

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The fuel cell ends were undamaged and only the fuel above the perforation was expelled (See Figure A-5). A brief fire followed the shaped charge detonation, but was quickly suffocated in the limited air. The peak tank pressure recorded was 63.7 psi (439 kPa), and the peak temperature in the personnel compartment was 689°F (365°C).

TEST NO. 4: TERA NO. BZ0731A4

1. Conditions:

Date: 31 July 1984

Fuel: 50 gal. (189 liters) of neat diesel

Fuel Temperature: 42°F (6°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Closed

Fan: On

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. A vigorous pool fire and ground fire was produced and temperatures in the personnel compartment peaked at 1966°F (1074°C) (See Figures A-6 and A-7). An attempt to extinguish the fire with a fire extinguisher was unsuccessful. However, the fire was easily suffocated by closing the rear door. Tank pressure peaked at 90 psi (620 kPa) and pressure in the personnel compartment reached 11.3 psi (78 kPa).

TEST NO. 5: TEST NO. BZ0803A4

1. Conditions:

Date: 3 August 1984
Fuel: 50 gal. (189 liters) of neat diesel
Fuel Temperature: 38°F (3°C)
Shaped Charge: 90-mm HEAT, M371E1
Armor: 1.5-in. (38-mm) aluminum
Door: Set to blow open
Fan: On
Suppression System: Not applicable
False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The end of the fuel cell opened along the weld, and all the fuel drained onto the floor (See Figure A-8). An intense pool fire resulted, but there was no ground fire. After several minutes of intense burning, the fire was suffocated by closing the rear door. Fuel tank pressure peaked at 61 psi (42 kPa), and the high temperature in the personnel compartment was 1576°F (858°C).

TEST NO. 6: TERA NO. BZ0803A4

1. Conditions:

Date: 21 August 1984
Fuel: 50 gal. (189 liters) of diesel fuel with 0.2 wt% AM-1 additive
Fuel Temperature: 60°F (16°C)
Shaped Charge: 90-mm HEAT, M371E1
Armor: 1.5-in. (38-mm) aluminum
Door: Open
Fan: On
Suppression System: Not applicable
False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The end welds of the fuel cell split, and all fuel was emptied. An intense fire developed that was extinguished by closing the rear door (See Figure A-9). The fire suffocated in about 1 minute. Tank pressure peaked at 215.8 psi (1.49 MPa), and the high temperature in the personnel compartment was 1439°F (782°C).

TEST NO. 7: TERA NO. BZ0828A4

1. Conditions:

Date: 28 August 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.2 wt% AM-1 additive

Fuel Temperature: 65°F (18°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Set to come open

Fan: Off

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. An intense fire resulted that melted one end of the fuel cell. There was no ground fire. After several minutes, the rear door was closed and the fire suffocated quickly. The peak fuel cell pressure was 70 psi (483 kPa), and the high temperature in the personnel compartment was 1579°F (859°C).

TEST NO. 8. TERA NO. BZ0906A4

1. Conditions:

Date: 6 September 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.2 wt% AM-1 additive

Fuel Temperature: 38°F (3°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Set to come open

Fan: Off

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The door did come open as a result of the blast pressure. The fuel cell end welds split, and all fuel emptied onto the floor. Only a very small pool fire developed that appeared to be associated with aluminum debris from a previous test (See Figure A-10). The fire was easily extinguished with a fire extinguisher. The peak fuel cell pressure was 130 psi (896 kPa), and the high temperature in the personnel compartment was 91°F (33°C).

TEST NO. 9: TERA NO. BZ0921A4

1. Conditions:

Date: 21 September 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.35 wt% AM-1 additive

Fuel Temperature: 61°F (16°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Ramp down

Fan: On

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The fuel cell end welds were split, and all fuel was expelled. No pool fire was produced, and only a momentary increase in temperature was recorded (See Figures A-11 and A-12). The peak fuel cell pressure was 124 psi (855 kPa), and the high temperature in the personnel compartment was 84°F (29°C).

TEST NO. 10: TERA NO. BZ1005A4

1. Conditions:

Date: 5 October 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.35 wt% AM-1 additive

Fuel Temperature: 58°F (14°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Ramp down

Fan: On

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The fuel cell end welds were split, and all fuel was emptied onto the floor. A small fire was started in the engine compartment across from the fuel cell and appeared to be associated with rubber-coated power cables (See Figures A-13 and A-14). The fire was easily extinguished with a fire extinguisher. The peak fuel cell pressure was 102 psi (703 kPa), and the high temperature in the personnel compartment was 108°F (42°C).

TEST NO. 11: TERA NO. BZ1012A4

1. Conditions:

Date: 12 October 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.35 wt% AM-1 additive

Fuel Temperature: 170°F (77°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Ramp down

Fan: On

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. An intense fire developed that could not be brought under control with a fire extinguisher. Suffocating the fire could only be accomplished by raising the ramp, and 37 minutes passed before this could be accomplished. By this time, the APC's roof had buckled and warped under the intense heat, making a complete suffocation impossible (See Figures A-15 and A-16). The peak fuel cell pressure was 120 psi (827 kPa), and the high temperature in the personnel compartment was 1619°F (882°C).

TEST NO. 12: TERA NO. BZ1026A4

1. Conditions:

Date: 26 October 1984

Fuel: 50 gal. (189 liters) of neat fuel

Fuel Temperature: 170°F (77°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Closed

Suppression System: Halon 1301

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. One end of the fuel cell was blown off, striking the valve of one of the halon dispensers. Both dispensers discharged, extinguishing the fire near the rear of the compartment. Fuel expelled through the open end of the fuel cell, circled around behind the halon

dispensers, and momentarily ignited. This fire died quickly when the fuel circled back into the halon cloud. The peak fuel cell pressure was 114 psi (786 kPa), and the high temperature in the personnel compartment was 737°F (392°C).

TEST NO. 13: TERA NO. BZ1102A4

1. Conditions:

Date: 2 November 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.2 wt% antimist additive

Fuel Temperature: 170°F (77°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Closed

Suppression System: Halon 1301

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. Both halon dispensers discharged, extinguishing the fire within a few milliseconds. The peak fuel cell pressure was 121 psi (834 kPa), and the high temperature in the personnel compartment was 132°F (56°C).

TEST NO. 14: TERA NO. BZ1115A4

1. Conditions:

Date: 15 November 1984

Fuel: 50 gal. (189 liters) of water

Fuel Temperature: 46°F (8°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Ramp down

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. The high temperature in the personnel compartment was 61°F (16°C), and the peak fuel cell pressure was 121 psi (834 kPa). The peak personnel compartment pressure was 9 psi (62 kPa).

TEST NO. 15: TERA NO. BZ1119A4

1. Conditions:

Date: 19 November 1984

Fuel: 50 gal. (189 liters) of diesel fuel with 0.35 wt% antimist additive

Fuel Temperature. 125°F (52°C)

Shaped Charge: 90-mm HEAT, M371E1

Armor: 1.5-in. (38-mm) aluminum

Door: Ramp down

Suppression System: Not applicable

False Floor: Removed

2. Results: The shaped charge perforated the aluminum armor and both sides of the fuel cell. One end of the fuel cell was blown off. Fuel was expelled through the open end and circled the APC in large flowing sheets, igniting as it circled into the heat round fireball. A momentary bright flash occurred which quickly subsided, leaving small fires around the interior perimeter of the PAC. These later grew into a large intense fire (See Figure A-17). No pressure gauge was used, but the high temperature in the personnel compartment was 2000°F (1093°C).

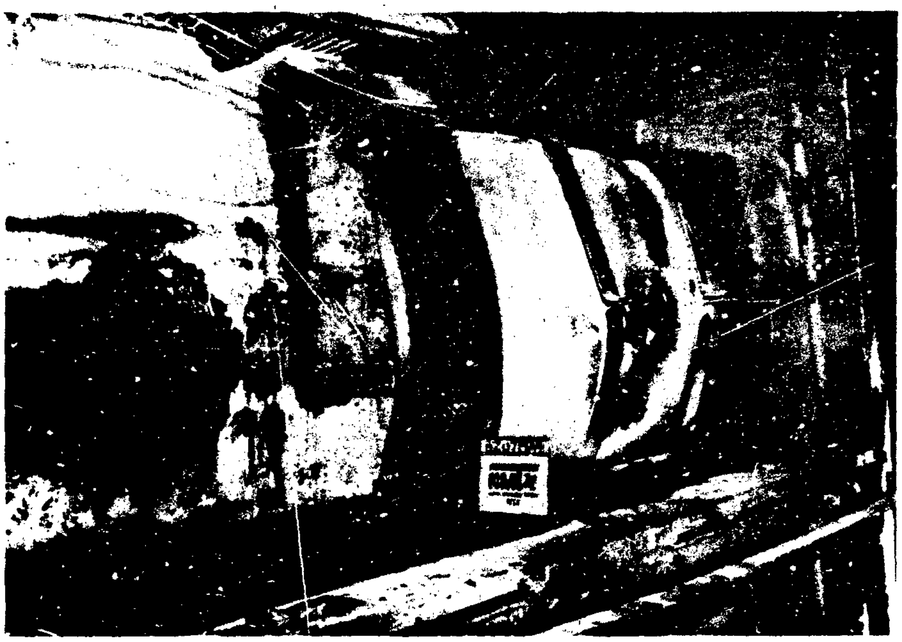


FIGURE A-1. FUEL CELL AFTER TEST NO. 1

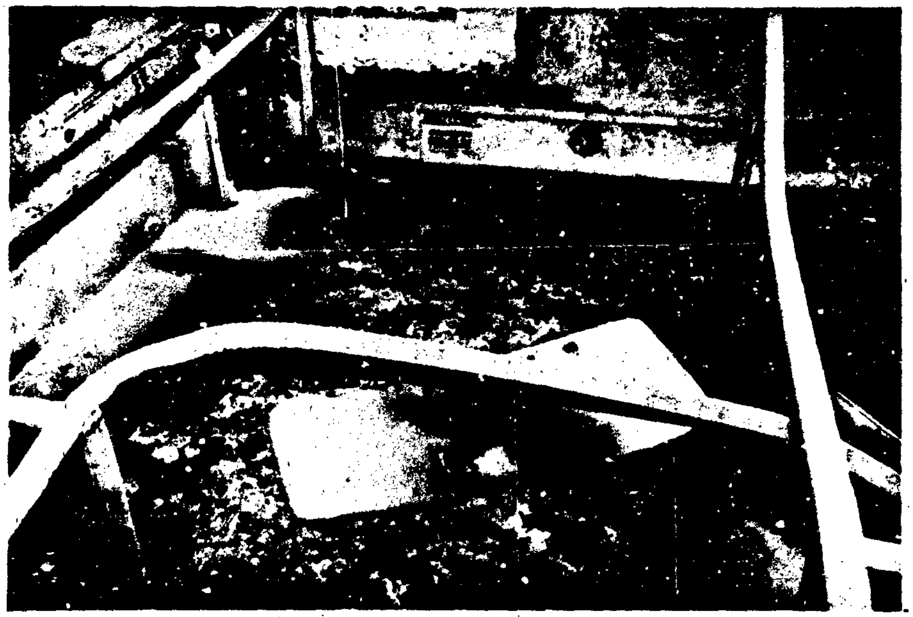
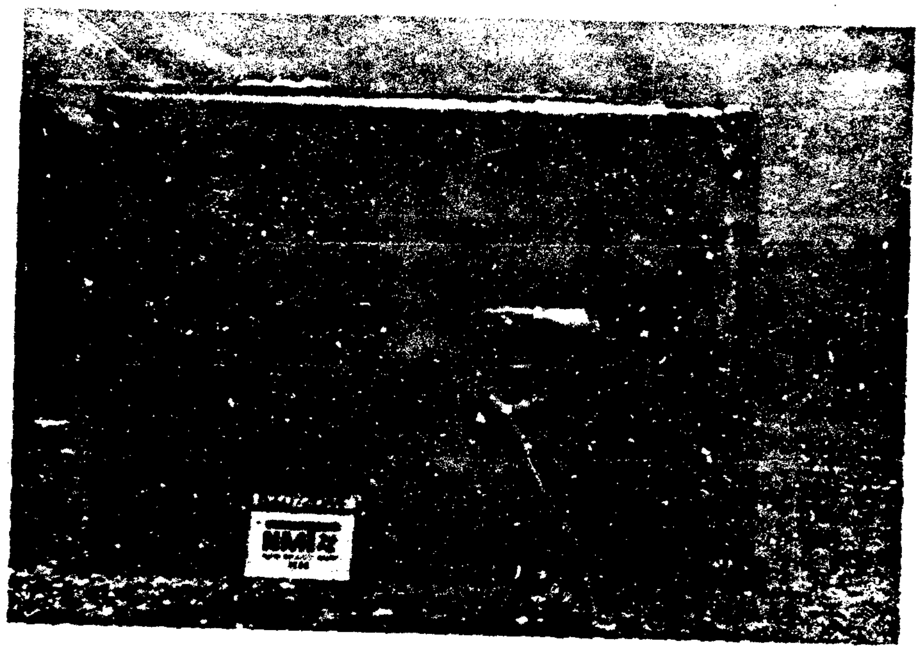


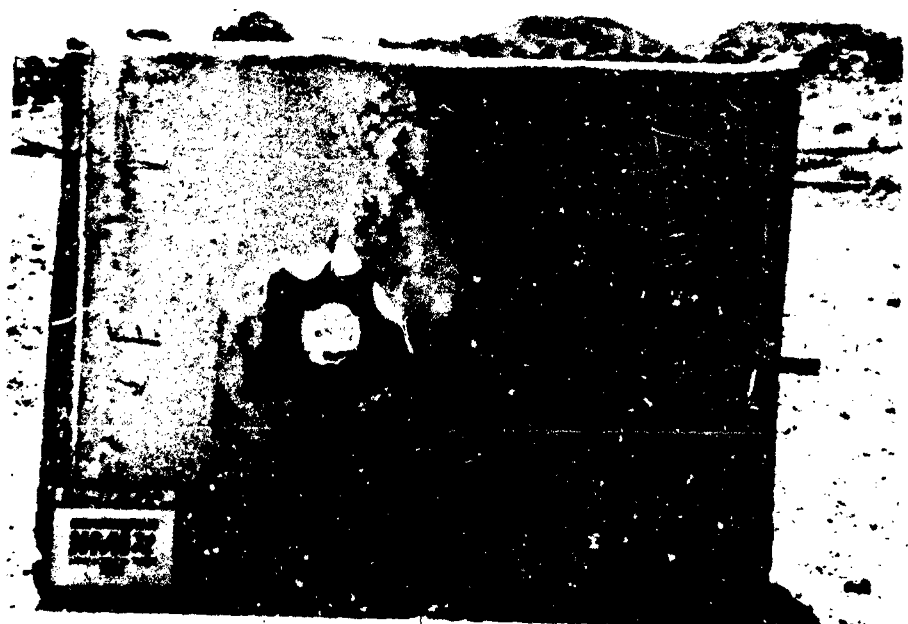
FIGURE A-2. END OF FUEL CELL AND FALSE FLOOR
AFTER TEST NO. 1

FIGURE A-3. END VIEW OF FUEL CELL AFTER TEST NO. 1

(SPEC27.A)



a. Entry Side With Reinforced End Seams



b. Exit Side (Note Broken End Seams)

FIGURE A-4. FUEL TANK 2

FIGURE A-5. END VIEW OF TANK 3

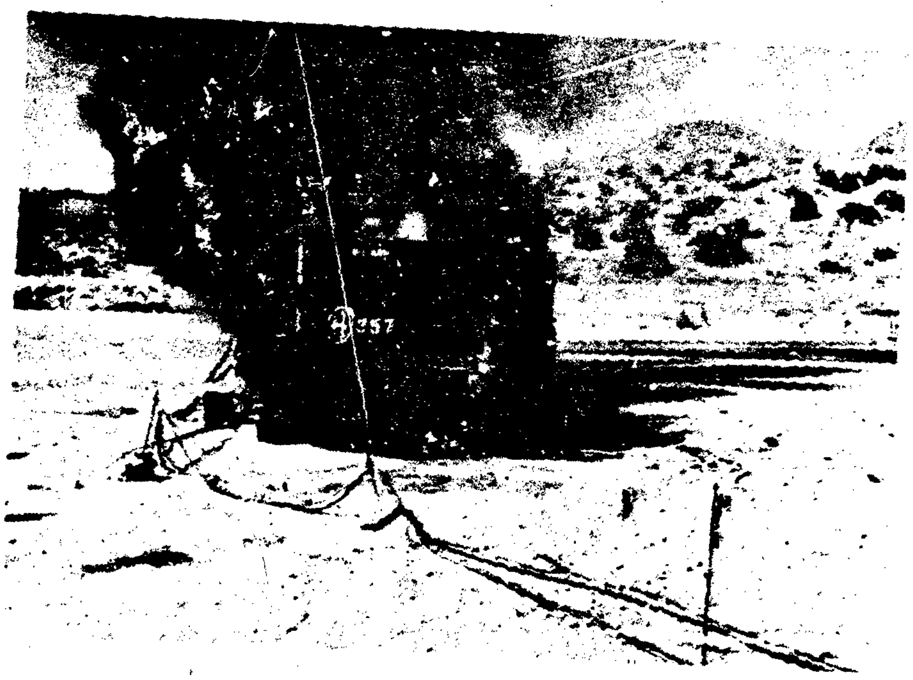


FIGURE A-6. FIRE AFTER TEST NO. 4

FIGURE A-7. FIRE AFTER FIRE EXTINGUISHER ATTEMPT

(SPEC27.A)

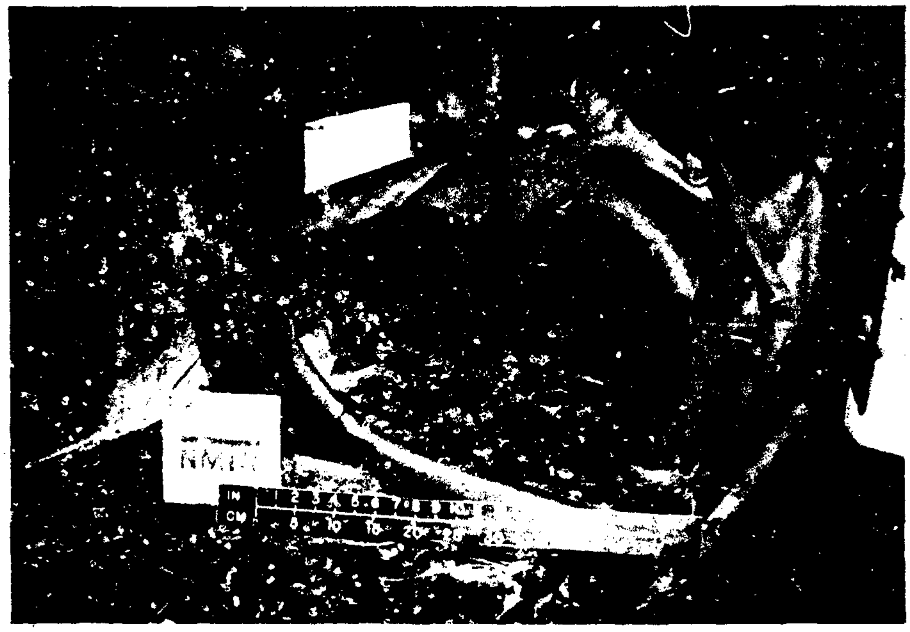


FIGURE A-8. END VIEW OF TANK 5

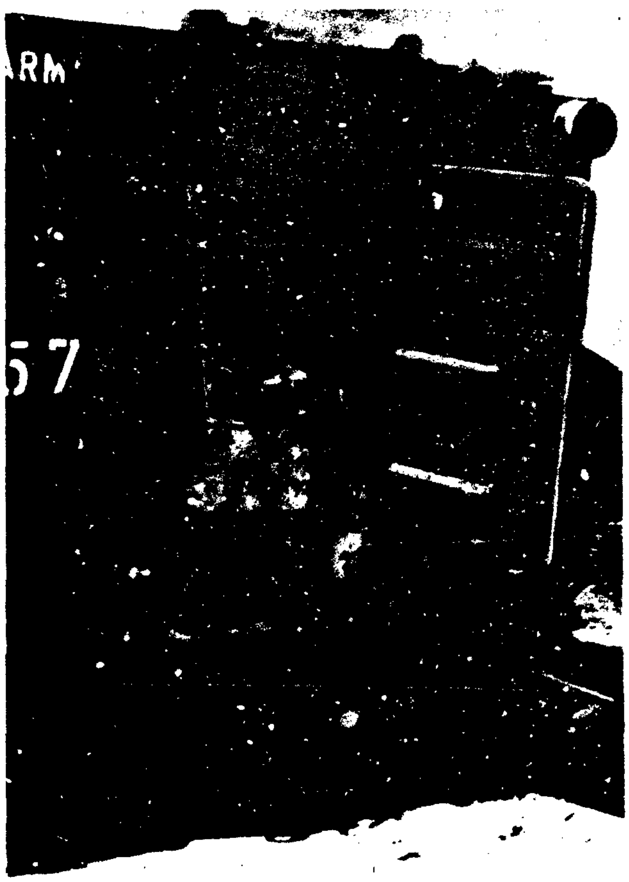


FIGURE A-9. FIRE AFTER TEST NO. 6

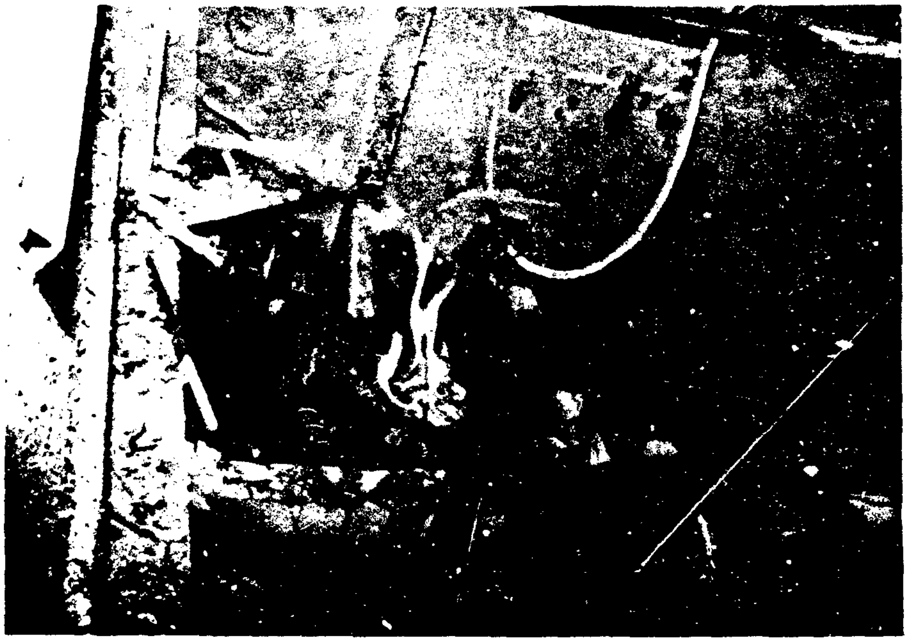


FIGURE A-10. SMALL FIRE AFTER TEST NO. 8

FIGURE A-11. FUEL CELL AFTER TEST NO. 9

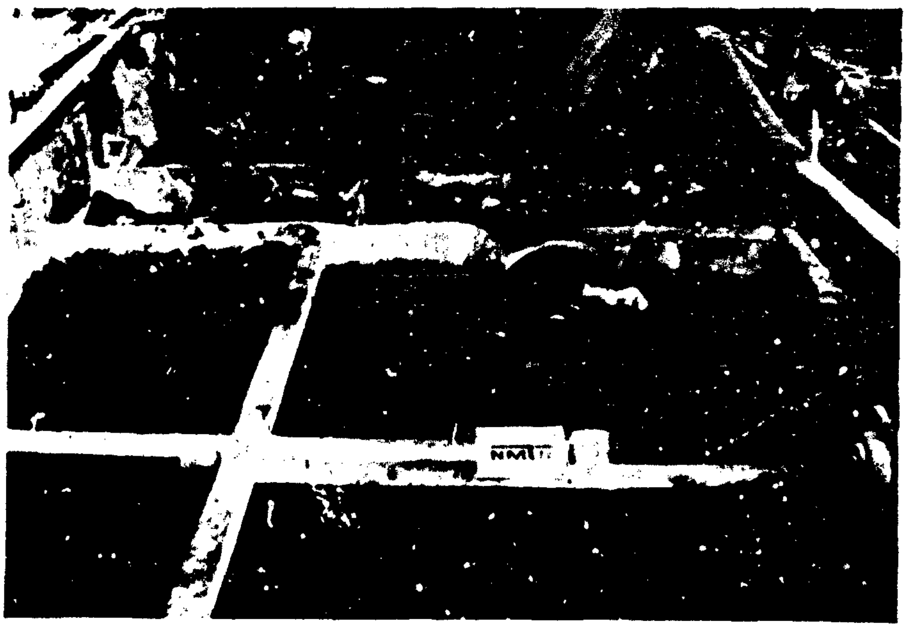


FIGURE A-12. NO FIRE AFTER TEST NO. 9

FIGURE A-13. SMALL FIRE AFTER TEST NO. 10

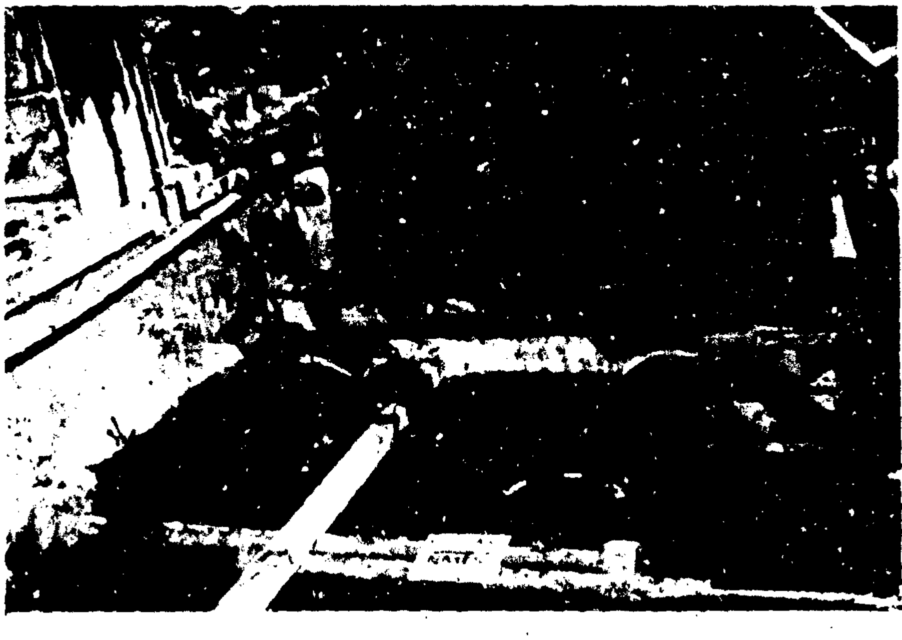


FIGURE A-14. SMALL FIRE AND FUEL AFTER TEST NO. 10

FIGURE A-15. FIRE AFTER TEST NO. 11

FIGURE A-16. FUEL CELL AFTER TEST NO. 11

FIGURE A-17. FIRE AFTER TEST NO. 15

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